Study of timing properties of Silicon Photomultiliers

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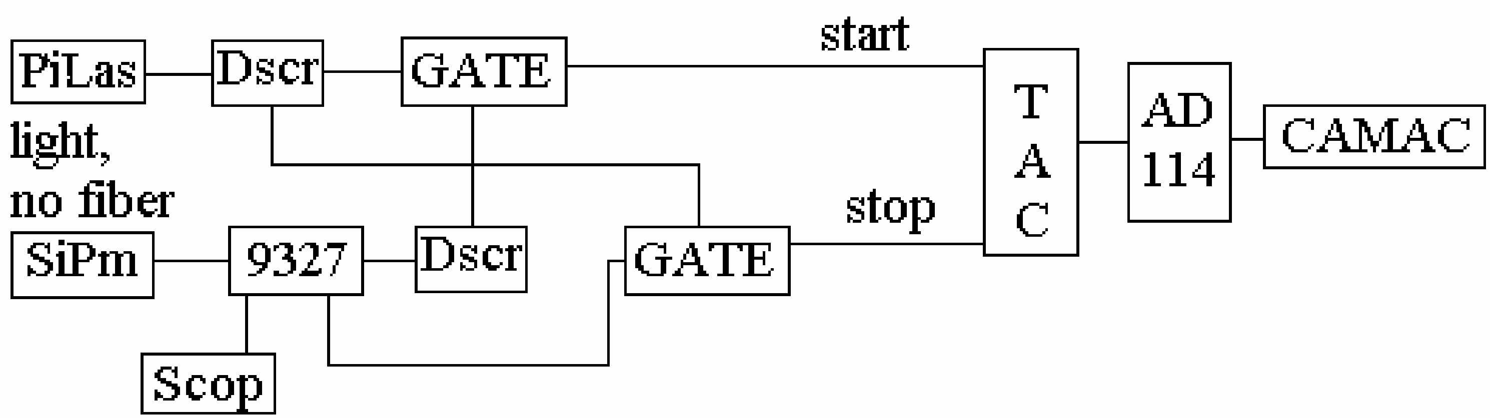
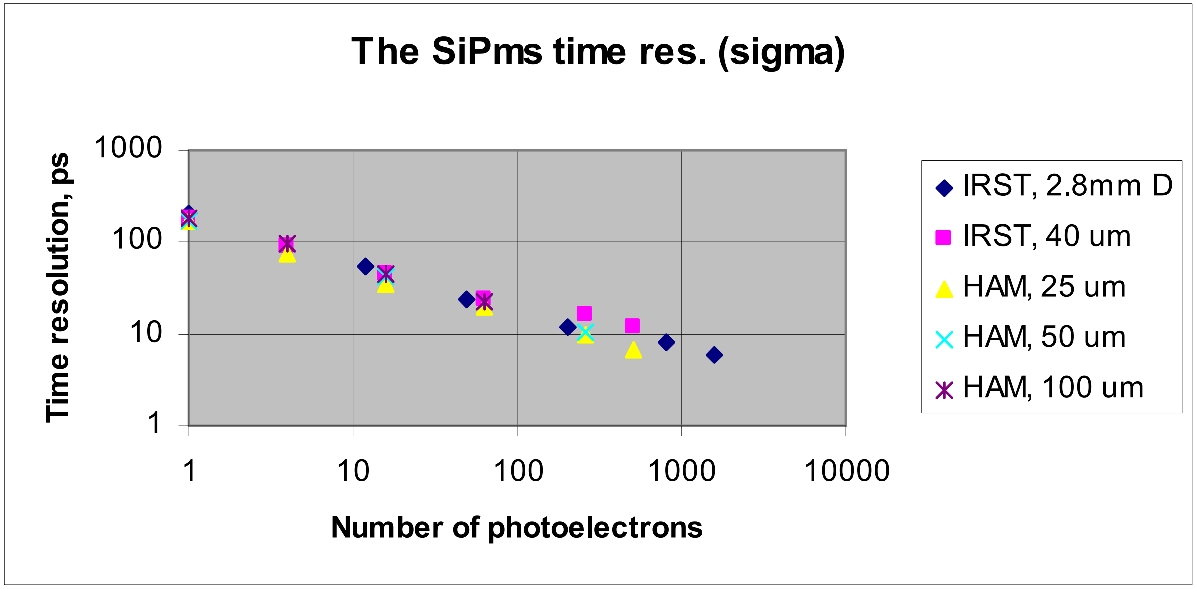
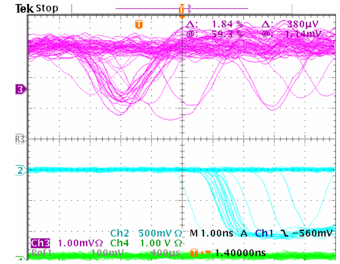
Fermilab's single photoelectron timing setup

- **PiLas (635 nm) laser provides fast light signal. Illuminates SiPM directly, without optical fibers.**
- **SiPM signal feeds into an Ortec 9327 Constant Fraction Discriminator through a 2 ns coax 50 Ohm cable.**
- **The timing measurement is made by an Ortec 567 Time to Analog Converter and AD114 ADC. This has 3.1 psec per channel resolution, with the electronic contribution to the resolution of about 2 psec.**
- **10 pf and 2kOhm in series was installed to differentiate the SiPm OUT signal because the 9327 accepts pulse width less than 5 ns.**

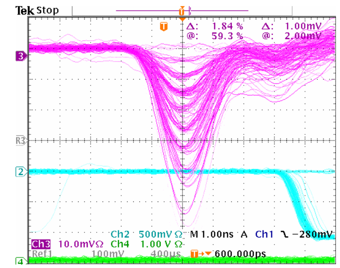


Dependence of the SPTR on number of photoelectrons (p.e.). Red (635 nm) PiLas laser light, 1 Volt of overvoltage, room T.

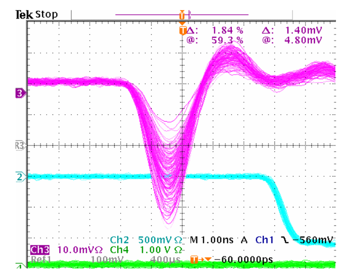




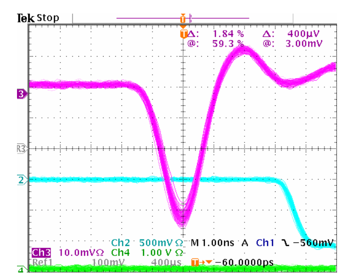
1 p.e.



4 p.e.



32 p.e.



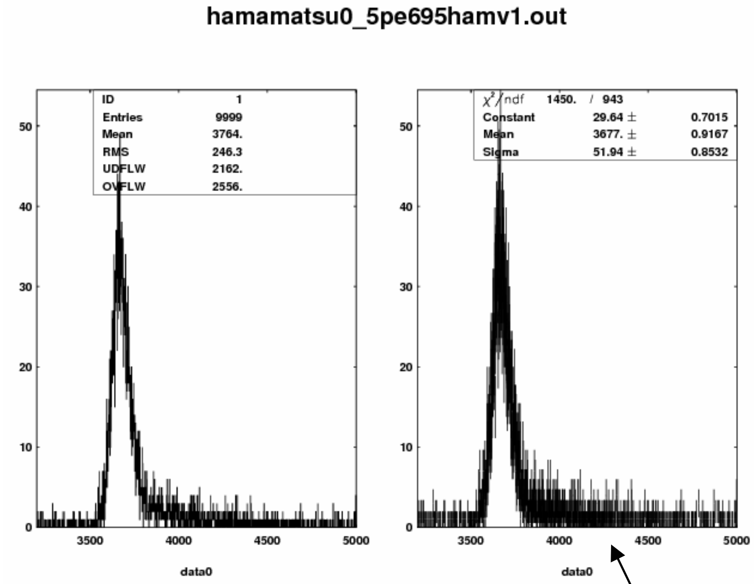
256 p.e.

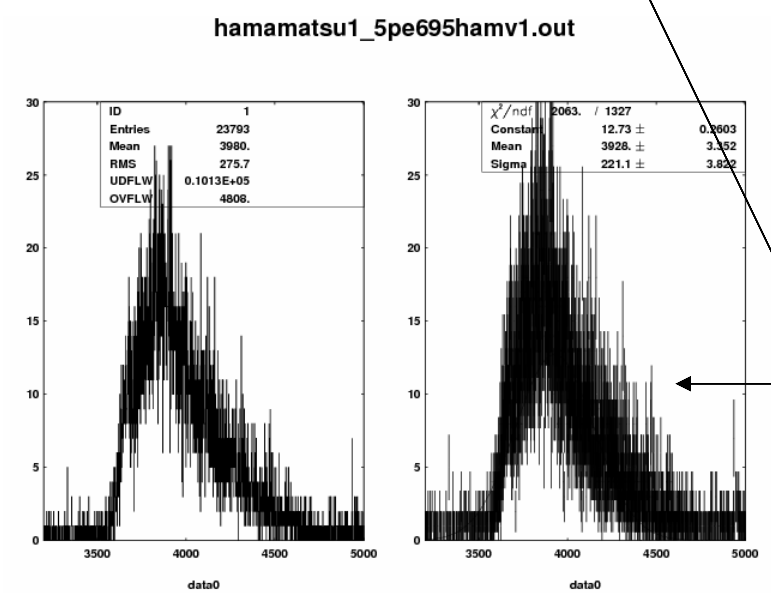
N phes	IRST 2.8 diam 50mk, 2500 pixs	IRST1mm2 40mk, 625 pixs	HAM-025U-10 25mk, 1600 pixs	HAM-050U-9 50mk, 400 pixs	HAM-100U-10 100mk, 100 pixs
1	210	178	164.6	171.4	182.2
3					
4		89	72.3		93.3
12	53.7				
16		44.6	35.1	42.5	45.8
50	24.2				
64		23.6	19.5	22	22.7
200	12				
256		16.1	9.9	10.2	
512		11.9	6.8		
800	7.9				
1600	5.9				

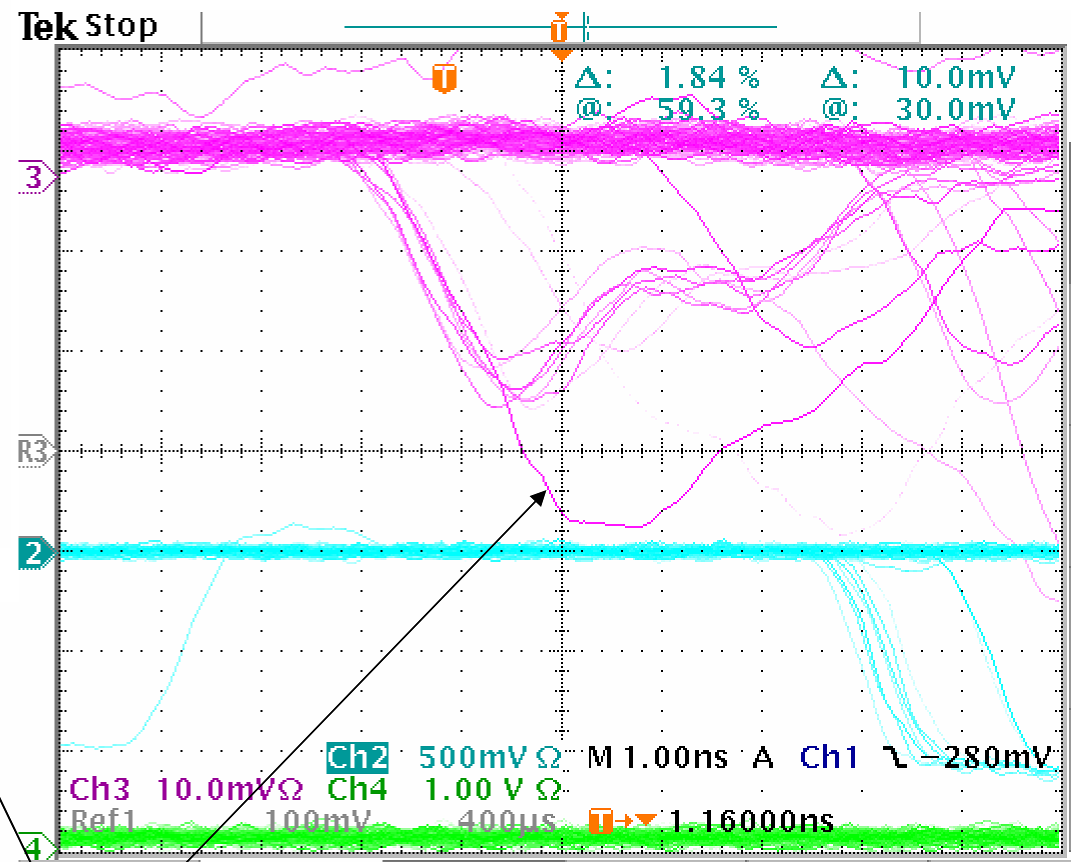
Conditions for Measurement of the SiPms time resolution.

- Single photoelectron's time spectra were taken with additional preamplifier (ORTEC VT120) to accommodate SiPm out signal into 9327 range.
- Decibel (dB) attenuators used instead of the preamplifier for high SiPms signals for the same purpose.
- Number of photoelectrons for SiPm's signals adjusted on the base of the single photoelectron amplitude spectrum.
- Most of the SiPms single photoelectron's time spectrum were taken with efficiency of registration of a few percent of the PiLas out pulsing rate. This corresponded mostly to single photoelectron. The contamination of double photoelectrons was neglected. Most of the data are taken with the 1 Volt of overvoltage.
- Temperature was under control with 1F accuracy during each run. Data were taken mostly at room temperature.
- Threshold of 9327 was on the level 0.5 phe. Some irregularities in single photoelectron time spectra were studied with the threshold of 1.5 phe.

Hamamatsu, sample 41, 0.5 and 1.5 pe threshold







The tail in the single photoelectron time spectrum mostly corresponds to doubled single photoelectron amplitude.

Comments

- Single photoelectron time resolution (SPTR) is on the level of 180 ps for the tested SiPms at room temperature and with about 1V of overvoltage bias.
- SPTR improved with overvoltage.
- Weak improvement of the SPTR with smaller pixel's size (more pixels for the same sensitive area) observed for Hamamatsu devices.
- The "inverse square root" dependence of the time resolution on the number of the photoelectrons ("fired pixels") clearly observed.
- Tail (or bump) in the single photoelectron spectra for few SiPms detected. It is mostly observed for Hamamatsu 1x1mm2 with 0.1x0.1 mm^2 pixel size
- The tail is relatively enhanced if threshold is 1.5 p.e. instead of 0.5 p.e. This means the tail is mostly due to doubled p.e. amplitude.
- The amount of events in the tail increased with overvoltage.
- The effect is most probably due to "optical crosstalk" in the SiPms.

Light absorption in Silicon*

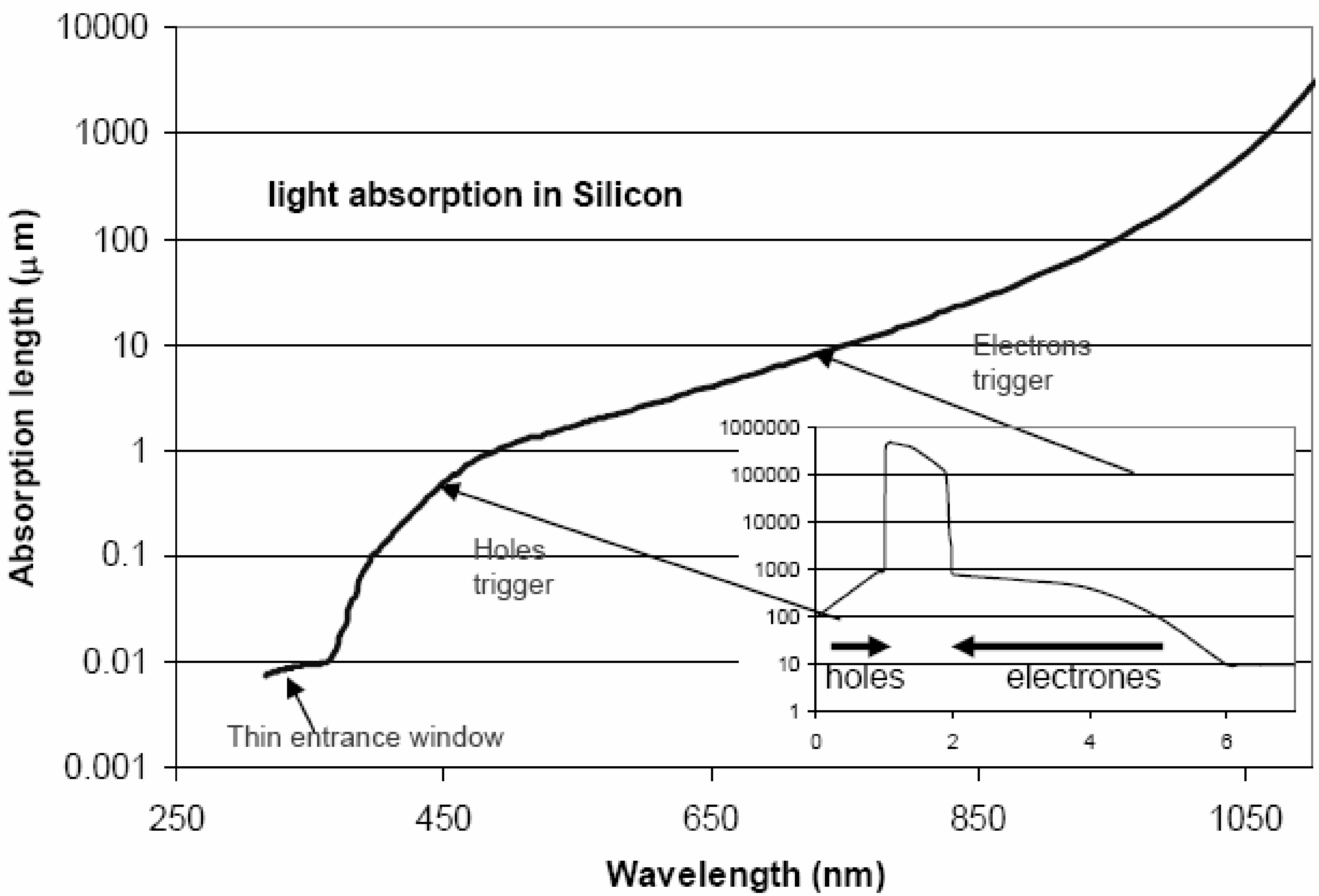


FIGURE 4. Light absorption in Silicon. The insert indicates the field configuration in a SiPM (see Fig. 1) and the drift direction of electrons and holes.

***from H-G Moser, MPI.**

Thoughts about SiPM time resolution and the tail.

- Light absorption length is 4 um for 635 nm (red) wavelength photons. The carriers produced in the avalanche are mostly electrons for Shallow-Junction, IRST SiPms in this case.
  - The effective length of 4 um corresponds to level of 100 ps. So this time is needed on average for electrons to reach the high field area to create avalanche. The time jitter for a single photoelectron output signal in SiPms should be of the same order.
  - If a few additional photons with more than 1 eV energy is produced by 100,000 electrons in the primary avalanche, then some of these will produce another charged carrier which need time to get into the high field to initialize an avalanche in neighboring pixels. The signal of this avalanche will be delayed with respect to the primary avalanche and overlaps in time with it.
  - The delay time should be of the order of hundreds to thousands ps depending on the distance between the high field area and place of the carriers originated, also as the carriers velocities. This will produce a delayed output, as seen in the data.
- The single photoelectron time resolution is different if we illuminate SiPMs by blue light. The light absorption length in that case is 100 nm for 400 nm wavelength photon.
  - Such photons produce mostly holes as carriers which initiates the avalanche. The velocity of the holes is 3 times less than for electrons but absorption length is 40 times less.
  - The combined time jitter due only to this factor should be about 10 times less as compared to red light.
  - This simple model does not include into consideration the time jitter due to avalanche development, lateral avalanche size, etc.